

DYNAMIC CHANGES IN SUBSCRIBER BEHAVIOR AND THEIR IMPACT ON THE TELECOM NETWORK IN CASES OF EMERGENCY

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ABSTRACT

The telecommunication network is recognized by the federal government as one of the critical national infrastructures that must be maintained and protected against debilitating attacks. We have previously shown how failures in the telecommunication network can quickly lead to telecommunication congestion and to extended delays in successful call completion. However, even if the telecom network remains fully operational, the special telecommunication demands that materialize at times of emergencies, and dynamically change based on subscriber behavior, can also adversely affect the performance of the overall telecommunication network.

The Network Simulation Modeling and Analysis Research Tool (N-SMART) has been developed by Bell Labs as part of its work with the National Infrastructure Simulation and Analysis Center. This center is a joint program at Sandia National Laboratories and Los Alamos National Laboratory, funded and managed by the Department of Homeland Security's (DHS) Preparedness Directorate. N-SMART is a discrete event (call level) telecom model that simulates capacities, blocking levels, retries, and time to complete calls for both wireline and wireless networks. N-SMART supports the capability of simulating subscriber reattempt behaviour under various scenarios. Using this capability we show how the network can be adversely impacted by sudden changes in subscriber behavior. We also explore potential solutions and ways of mitigating those impacts.

INTRODUCTION

We have previously found [1] a number of interesting results for wireline and wireless telecom networks under stress and failure conditions.

- Network congestion lasts until well after the causing disrupting event has subsided.
- Service providers should not place many key switches in the same central office. The failure of a

single office can cause ripple effects in blocking to reverberate throughout the entire network.

- Wireline and wireless networks in a metropolitan area support each other in times of trouble. As such, the presence of multiple networks enhances overall network communications, resiliency, even though they were not designed for that purpose.
- Since either network (wireline and wireless) is equally likely to suffer a disruption, the overall resiliency is best when each network carries relatively equal loads. Disruption of one carrying much larger load may congest the smaller network.
- This resiliency is caused by customer behavior in switching between networks when one is failed. But the switchover in demand onto the non-disrupted network may cause significant congestion in that destination network.

This last conclusion from our previous paper was one of the reasons that motivated the analysis in this paper. User behavior and changes to it can play a critical role in how a failure propagates during emergencies [2]. It also leads to potential mitigations by educating users on how to react in times of crisis.

In this paper, we investigate the resilience of the telecommunications infrastructure during emergencies (earthquakes, hurricanes, tornados flooding, etc.) where traffic surges and the telecom infrastructure can be damaged. The infrastructure scenario represents the state of the networks today, where the wireless network size roughly equals the wireline network size. To perform our study, we introduce a model for the telephony infrastructure for metropolitan service areas. Our goal is to develop a baseline functional model of the telecom system and then study the customer behavior in the presence of telecom and/or other infrastructure system failures and overloads.

We first introduce our simulation that represents a metropolitan area telecommunications network. Then, we describe the disruption and overload scenarios. We pre-

sent simulation results and compare the emergency scenarios in terms of network call carrying capacity and customer behavior. Finally, we conclude with a summary and future research directions.

N-SMART SIMULATION MODEL

N-SMART is a discrete event (call level) telecom model that simulates capacities, blocking levels, retrials, and time to complete calls for both wireline and wireless networks.

The simulation engine consists of algorithms which generate events related to calls, re-attempts, network failures, processor overloads, and simulation output. The call model across wireline and wireless networks and the interaction between the two networks based on subscriber behavior are central to the simulation [3][4][5].

END USERS ACCESS DISTRIBUTION

End users have a choice among alternate communication means made possible through the rapid advances in networking technology (wireline - copper, coax, fiber; and wireless - cellular, WiFi, WiMAX). At present we see some users with only wireline phones, other users with wireless phones only, and yet others with access to wireline and wireless phones at the same time.

Trends in recent years show that while the number of subscribers that rely exclusively on wireline access shrinks, the number of subscribers using wireless access is increasing at a faster rate. If this trend continues in the future, it would mean that a majority of subscribers will eventually have access to both wireline and wireless communication. The technology trend also promises to offer these users multiple modes of using their telecommunication venues.

THE REATTEMPT MODEL

First a typical call attempt arrives at a particular switch for a certain destination switch, as described by the traffic load and the traffic profile. The call is accepted and routed through the network (set up) if there are sufficient trunk and processing resources in the switch and the network. The call may be blocked if the called line is busy, or if the network is busy, which may be due to trunk blocking along the route of the call (direct route and alternate routes). The network can become busy due to switch blocking because of processor congestion, or network management blocking. If a call is blocked, the caller may abandon the call set-up request or re-attempt later, on either the wireline or wireless network. Routing decisions are based on the originating and terminating switches of the call. A call is referred to as incomplete if the call attempt results in no answer, line busy, or network busy. An incomplete call may be abandoned or re-

attempted. A reattempt model based on [6] is used in the simulation. According to this model, a call would reattempt with a certain reattempt probability after an exponentially distributed reattempt time. Reattempt parameters are a function of whether the call was blocked due to no answer, line busy, or network busy. These dispositions determine how fast reattempts will be made. The historical reattempt model parameters [6] are shown in Table 1. The probability row in Table 1 indicates that 13% of all calls are met with no answer (or an answering machine) and 6% of calls are met with a busy tone.

Table 1. Reattempt Model Parameters

	No Answer	Line Busy	Network Busy via Congestion
<i>Probability</i>	13%	6%	Dynamically computed
<i>Retattempt probability</i>	61%	72%	86%
<i>Mean time to reattempt</i>	3 Minutes	18 Minutes	24 Minutes

The reattempt model shown in Table 1 is applicable when there is only one telecommunication network available. The goal of this paper is to investigate the inter-dependencies between wireless and wireline systems as a function of these customer behaviors. When two different network technologies are available, a caller might retry an incomplete call in the alternate network. The retry would occur with the same pair of endpoints or may happen after changing one or both of the endpoints, e.g., wireline endpoint to wireless endpoint and vice versa, with a total of 4 options. This depends, of course, on the availability of options for the end-user:

- For an initial wireline user, is a wireless phone available? This will depend on the wireless penetration of the market for each user type in the metropolitan area.
- For an initial wireless user, is a wireline phone available? If they are on the move (i.e., not at home or work), then they might not have access to a wireline phone.

The endpoint for the destination can also be changed based on the availability of an alternate phone number and the caller's knowledge of it. N-SMART incorporates a detailed probabilistic model to reflect these network switching events for reattempts. In fact, this switching of endpoints shifts the load from one network to the other network. For example, for a call blocked in the wireline network because of a failed switch, the callers would reattempt their calls over the

wireless network. This results in a shift of load from the wireline to wireless network. If such calls are successfully completed over the wireless network, we can say that the wireless network alleviates the problem in the wireline network, and hence, increases the resilience of the telecommunications infrastructure. On the other hand, if these reattempt calls congest the wireless network, and cause the blocking of calls in this network, we can say that the wireline network impacts the performance of the wireless network negatively. In the following section, we investigate this interaction between networks in detail using the N-SMART simulation model.

THE METROPOLITAN NETWORK MODEL

We have analyzed a number of metropolitan areas in the course of our work. In this paper, we chose a medium sized metropolitan area, where there are as many wireline subscribers as wireless subscribers. In addition, we also assume that the traffic created by each wireless subscriber equals the traffic created by each wireline subscriber in Erlangs. Based on current trends; this is a reasonable representation of the expected future network.

Metro Network: 900,000 wireline subscribers and 900,000 wireless subscribers

NETWORK ASSUMPTIONS

We design the Metro network to carry the normal expected traffic at peak hour. We use high usage trunk groups [7] to carry the bulk of the traffic and then allow any blocked calls to go over final trunk groups to the Local Tandems (LTs) or Access Tandems (ATs) based on the type of call. The design goal was to guarantee a maximum blocking of less than 1% on any given route. In addition, we build high usage trunks only if there is sufficient traffic to utilize the trunk group.

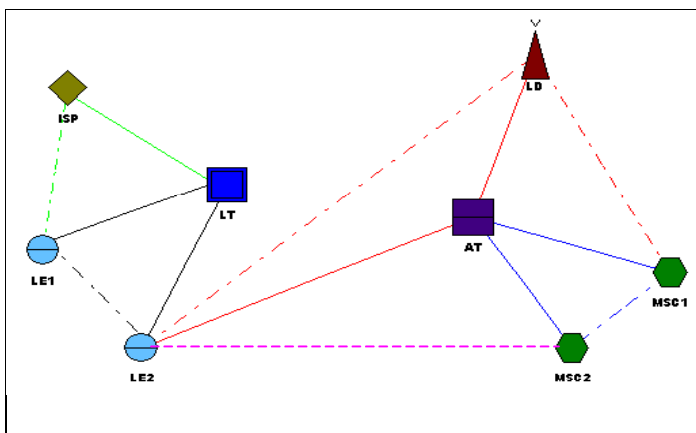


Figure 1. Traffic Routing Model

LE = local exchange LT = local tandem LD = Long Dist.
MSC = mobile switch center AT = access tandem ISP = Internet

Figure 1 shows the routing allowed in the network. The dashed routes in Figure 1 are high usage routes and the solid routes are the final routes. The dashed and solid routes of a given color show the routing rules for that traffic type. Therefore, looking at the blue trunks, we see that traffic between two Mobile Switch Centers (MSCs) is sent over a high usage trunk group, and in case that high usage group is not available, the call is sent via the corresponding ATs of the two MSCs.

The normal traffic pattern in a telecommunications network changes as a function of the time-of-day. During certain hours of the day, the traffic is at a maximum while during other hours it is very small. This is represented by a traffic profile, as shown in Figure 2, in the N-SMART model.

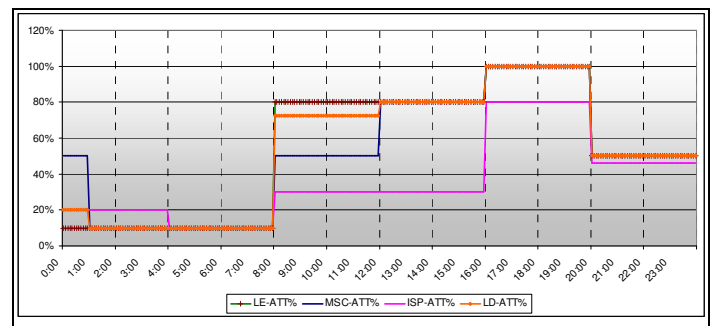


Figure 2. 24-Hour Traffic Profile

Figure 2 shows the traffic profile during a typical 24-hour period.

HISTORICAL DISRUPTION SCENARIOS

During a disaster (or similar) scenario, telecom users are impacted by events that unfold around them and they respond in ways that almost invariably cause some stress on the telecom network. Oftentimes, these changes are difficult to predict ahead of time. However, in many instances, it is possible to foresee the trends that are likely to occur. It is therefore possible to develop disaster response plans that would incorporate mitigation strategies that can minimize the resulting disruptions.

To show how a disaster can affect the telecom network, we present the following actual events and how they led to varying levels of network disruptions.

1. **Stock Market Crash 1987** – This was the precipitous fall of the stock market in 1987 that was largely attributed to automated panic selling.
 - a. Heavy distributed call load.
 - b. Broker 800 numbers in high use.
 - c. Above-normal Switching Control Point (SCP) blockage.

- d. Heavy specialized load impacted the signaling network and led to degradation of other services.
2. **First World Trade Center (WTC) Bombing of 1993** – This was the first bombing of the World Trade Center in 1993.
 - a. No damage to the 3 WTC switches at the time.
 - b. Telecom congestion seen on WTC switches. Heavy load of incoming calls.
 - c. No single number experienced a focused overload.
 - d. Complaints regarding E911 services. Overload on E911 operators.
3. **Olympic Park Bombing in Atlanta, 1996** – Even though this was a minor event, it sheds light on how events affect telecom networks in unpredictable ways.
 - a. Congestion the morning after the Olympic park bomb. Cause unknown.
 - b. Incoming calls to one number were causing overload.
 - c. Root Cause: Atlanta paper held morning edition to add bombing coverage. This led to many non-delivery calls from customers.
4. **WTC Disaster of September 11, 2001** – This disaster combined user overload behavior with extensive damage to the telecom infrastructure.
 - a. 6 total switches were lost in this event.
 - Two switches in WTC buildings.
 - Four in 140 West Street from flooding due to firefighting efforts.
 - b. Operations network seriously impacted
 - c. Network alarm storm; largest alarm storm ever witnessed.
 - d. Call demand sustained 2 times overload for 24 hours
 - e. Wide-spread trunk busy due to heavy load
 - f. Lost connectivity to Manhattan switches (72 offices)
 - g. E911 services severely overloaded
5. **Houston Evacuation (Hurricane Rita), 2005** – This event shed some light on consequences during a large-scale evacuation in anticipation of an impending disaster.
 - a. With most subscribers on the move, there was an overload of the wireless network.
 - b. The base stations could not service all the subscribers in high concentration points on the highways.

SIMULATED SCENARIOS

In the forthcoming simulations we consider the following scenarios:

1. **Baseline Condition** – This shows the traffic pattern under normal operating conditions.
2. **Case 1: Headline News Condition** – This is like the San Francisco Earthquake, or the WTC bombing where the call volume increases significantly and subscribers become more persistent in reattempting until they are able to get connected.
3. **Case 2: Major Evacuation** – This is modeled after the Houston evacuation. In this scenario, the wireless traffic is overloaded, and in addition, wireless subscribers are not permitted to switch to wireline devices on the originating side, since they are presumably on the road and in their cars.
4. **Case 3: Emergency Condition** – This is modeled after the WTC bombing of 1993 where the E911 services are overloaded causing a targeted overload in call volume on the wireline network. Of course subscribers are permitted to call 911 from whatever device they choose.

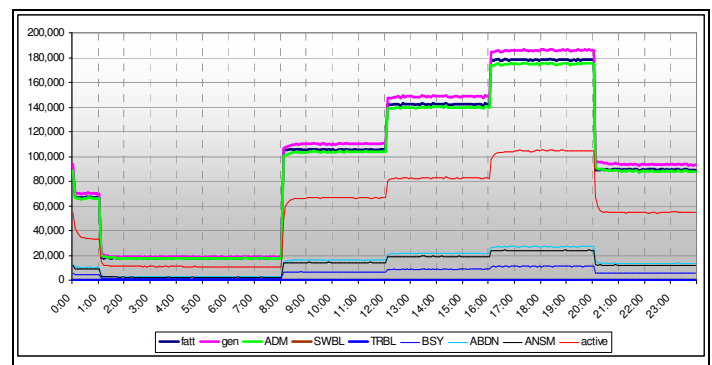


Figure 3. Baseline Calls

These scenarios show how traffic is affected as a result of user behavior in heavier call volume, more persistent calling and the ability to use one or both networks given the conditions at hand. First, we show the baseline traffic pattern for our network under normal operating conditions (Figure 3).

There are 9 statistics in Figure 3 as follows:

1. FATT - first attempts of calls
2. GEN - total calls generated
3. ADM - admitted calls which complete
4. SWBL - switch blocked calls
5. TRBL - trunk blocked calls
6. BSY - calls which end to busy line
7. ABDN - calls which are abandoned
8. ANSM - calls routed to an answering machine
9. ACTIVE - total active calls across the network

All of these statistics, with the exception of ACTIVE, are call counts within 5-minute intervals. ACTIVE is a snapshot of the total number of calls at the sampling instant. Figure 3 shows call statistics for the baseline scenario, also representing the 24-hour traffic profile for our metropolitan area. The busy hour is from 16:00 (4 PM) to 20:00 (8 PM). Under normal conditions (no disruptions), most first attempts are admitted and complete except for a fraction encountering no answer or busy. But most of them are retried and complete on subsequent attempts if the user does not abandon.

We present a discussion of the simulation results in the following sections. Our objective is to compare how each network is affected by the failure condition, and, where instructive, the impact on the individual sub-networks within the overall network

CASE 1: HEADLINE NEWS CONDITION

This condition envisions a sudden rise in call volume on all telecom networks. This is also accompanied by a more persistent re-attempt behavior on the side of the users. This means the following:

Table 2. Case 1 Reattempt Model Parameters

	No Answer	Line Busy	Network Busy via Congestion
Reattempt probability	80%	80%	80%
Mean time to reattempt	3 Minutes	10 Minutes	5 Minutes

In addition, the new traffic profile is shown in Figure 4. The red line indicates the normal peak hour traffic level. Overload traffic condition occurs at 14:00 and continues until 21:00, where traffic returns to the peak normal traffic.

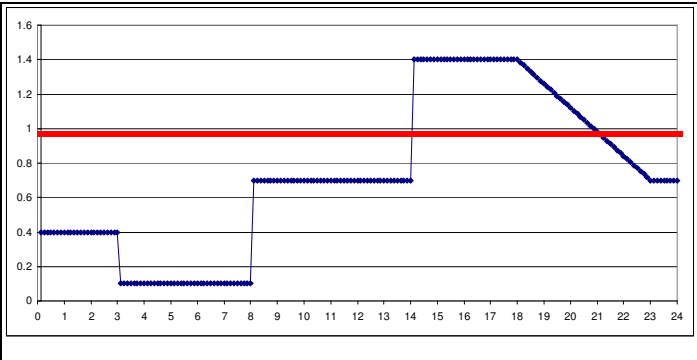


Figure 4. Traffic Profile for Case 1

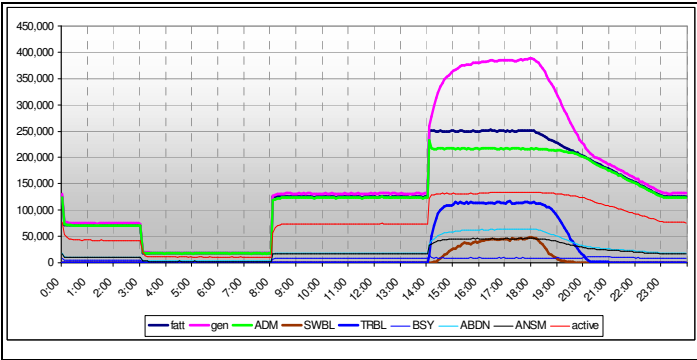


Figure 5. Case 1 Headline News - Overall traffic

Figure 5 shows the overall traffic results for Case 1. Note the clear rise in generated calls at 14:00, which leads to a rise in switch blocking and trunk blocking. This occurs as a result of increased demand even though the network does not suffer from any failure at that time.

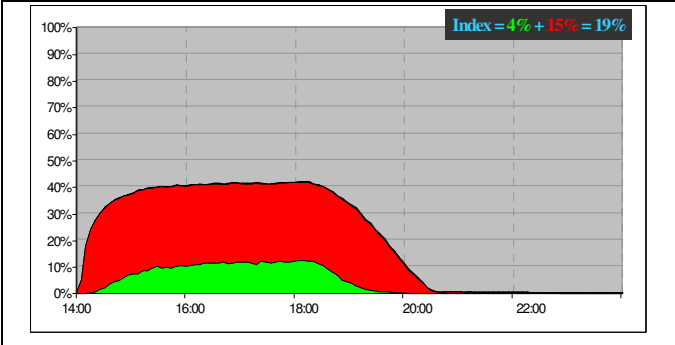


Figure 6. Case 1 Headline News - Overall Blocking

Figure 6 shows the impact of the traffic overload in terms of blocked calls. It shows the blocking caused by switch (green region) and trunk (red region) blocking. The regions in the plot are cumulative, therefore, the overall height of the curve indicates the total blocking at any given time. We see that call blocking rises slightly above 40% at peak blocking conditions.

CASE 2 – MAJOR EVACUATION

The factors that lead to traffic overload in this case are the number of users that are confined to use their wireless phones without wireline access. We model an (2 times) overload of wireless traffic and also disable wireless users on the originating side from switching to their wireline phones.

Figure 7 shows the impact of traffic overload during the evacuation on the entire network. Again we see the switch blocking and trunk blocking become a significant factor quickly after the traffic overload. This simulation was done with normal reattempt behavior. However, we also tested another scenario with frantic reattempt and we observed greater blocking at peak hours.

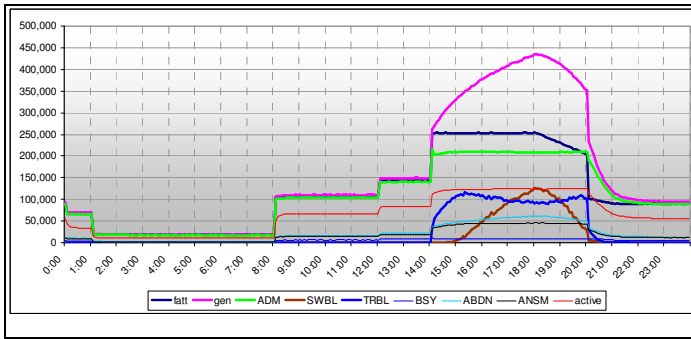


Figure 7. Case 2 Major Evacuation - Overall traffic

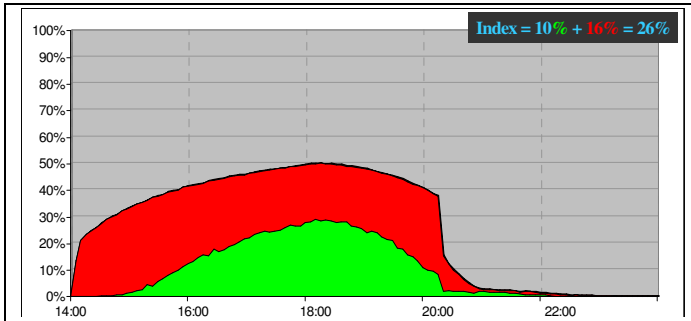


Figure 8. Case 2 Major Evacuation - Overall Blocking

Figure 8 shows the overall temporal blocking for Case 2. Total blocking reaches 50% at peak level. Switch blocking also is more of a factor in this case.

CASE 3 – EMERGENCY CONDITION

We model the E911 (2 times) overload by overloading the traffic on the major wireline switches. This leads to an overall increase in traffic, which is substantially, less than a 2 times global overload. However, it also simulates the uneven distribution of the overload and the greater burden posed on E911 service centers. We also assumed a frantic reattempt behavior, as would be expected for blocked emergency calls.

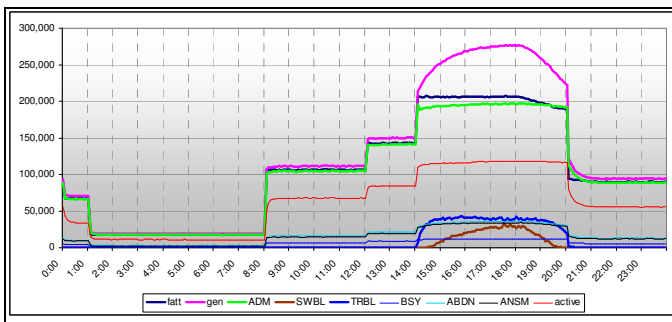


Figure 9. Case 3 E911 Overload - Overall traffic

Figure 9 shows the overall impact on the entire network from the E911 overload.

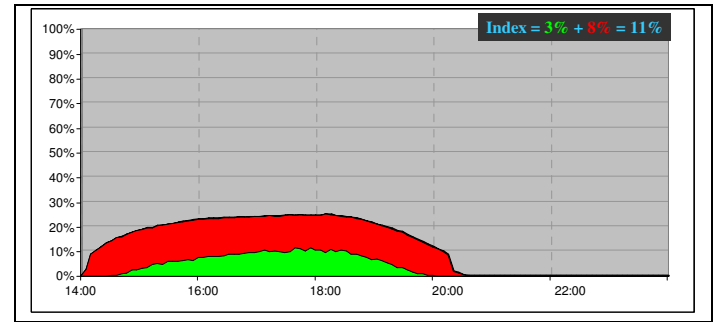


Figure 10. Case 3 E911 Overload – Overall Blocking

Figure 10 shows the overall temporal blocking for Case 3. Peak blocking reaches 26%. Overall traffic blocking in this scenario is much less than in Cases 1 and 2.

MITIGATION OPTIONS

The previous sections showed significant congestion resulting from typical customer behavior during emergencies. We studied several mitigation scenarios ranging from changing customer behavior to ones affected by the service providers.

To illustrate the dependence of network degradation on subscriber behavior, we show how network blocking is affected by the probability of subscribers reattempting their calls, and then how that is further impacted by the average waiting period before a reattempt is made. The results are shown in Figure 11 which corresponds to Case 1. Similar results are expected for the other Cases.

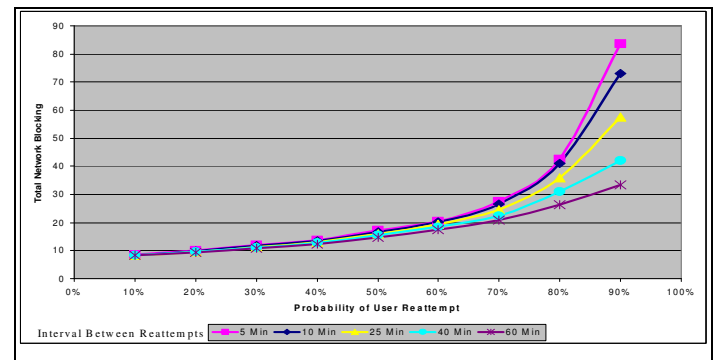


Figure 11. Network Blocking vs. User Reattempt Behavior

This mitigation option has the disadvantage of relying on the users to change their behavior. This may not always be possible or practical. Other mitigation solutions that do not rely on customer behavior include freeing up less critical telecom resources in favor of allowing more critical ones to have a better chance of completing.

One of the questions that must be answered is how to determine which traffic (and telecom resources) is less critical and is subject to pre-emption. This is a subject in its own right and it goes beyond the scope of this paper. Nonetheless, the priority of traffic types obviously de-

depends on the scenario at hand. Therefore, in cases where it is critical to reach emergency operators locally, the telecom providers may choose to drop most or all of the Internet Service Provider (ISP) traffic that uses modems during the peak conditions. This will free up some circuits that can be used in completing more critical voice calls. In addition, long distance traffic can be reduced in favor of allowing local traffic to complete more readily.

We simulated these cases by completely dropping ISP traffic and reducing long distance traffic to 50%. The results showed varied improvements for the 3 Cases.

Table 3. Effects of Reducing ISP and LD Traffic

	Case 1	Case 2	Case 3
<i>Original Overall Blocking</i>	22.7%	34.4%	12.2%
<i>Blocking with 50% LD and no ISP</i>	10.3%	24.3%	9.9%

Another option in traffic mitigation is to enact various network management controls. The disadvantage for this method is that such controls may not always be available depending on the type of traffic. Additionally, the enactment of these controls usually requires access to a network operations center (NOC). This may prove difficult in cases where the NOCs are unavailable or damaged, as in the September 11, 2001 scenario.

SUMMARY AND CONCLUSIONS

We have shown how changes in subscriber behavior can have a decisive impact on the operation of a telecom network in this paper. Our simulation Cases support the following conclusions:

- Changes in subscriber behavior drive network congestion during emergencies.
- If re-attempt probability can be decreased and the time between reattempts can be increased on the part of subscribers, network congestion is reduced dramatically. One way to accomplish this is to encourage subscribers via broadcast radio and television to use their phones selectively. This reduces traffic load and increases the probability of successful call completion.

- Frantic reattempt behaviors (those with high probability of a reattempt, and a smaller wait interval between reattempts) are especially degrading to overall network performance.
- Reducing less critical traffic in an emergency condition (like ISP and long distance) can help reduce overall blocking during peak hours of use.
- Lastly, network management controls are not usually executed within local metropolitan area networks as they are in long distance networks. Adopting network management controls in local networks would be another way to reduce networks congestion. This might require expensive modifications to switches, which are not likely for legacy networks. For newer IP based networks, these management controls should be considered.

FUTURE DIRECTIONS

So far we have been dealing with circuit switched voice networks, which dominate today in metropolitan carrier networks. More and more telecommunication networks are starting migration to IP-based networks, supporting VOIP (Voice Over IP). In addition, the network architecture is changing to support the requirements of newer and more advanced services. The modeling of this network evolution and its impact on the critical infrastructure are future goals in our study.

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